Content Background for Sound

Sound is everywhere and teachers are bombarded with it continually! You must corral a herd of lively, energetic, sound makers every day in your class. First graders are noisy! It is not easy controlling their sound levels and teaching first graders about sound is no easy task. Sound is something that they know about, use, and think they understand. You may be in the same situation. This document will ask you questions about sound that you may have never considered before. You will do the same for your students when you teach these lessons. However, this document and your experiences here will give you "extra" information and opportunities to build your understanding about sound so that you can be better prepared to facilitate the sound lessons with your students.

STOP ***Stop and Think:*** What do all sound makers have in common?

Vibrations

If you were to go through your classroom or home and find things that are making a sound, what would they all have in common? If you lightly touched the object that is making sound you would feel vibrations. Touch a speaker to your sound system, your throat while you are talking, or your computer when it is running. They all produce vibrations. Sometimes it is possible to see the vibrations—a string on a guitar after it is plucked, a cymbal once it is struck with a stick, an uncovered speaker when the music is loud. These are all examples of vibrations that you can see. Other sound makers have vibrations that you cannot see. Consider a flute or when you blow over the top of a soda bottle to make a sound. What is vibrating? The bottle and the flute are certainly vibrating but they are not the first thing to vibrate. The way you blow into a flute or over the top of a bottle causes the air inside to vibrate. The vibrating air the causes anything it touches to vibrate too. We hear sound because something is vibrating. Pinch a vibrating guitar string and the vibrations stop—and so does the sound!

STOP ***Stop and Think:*** Do all vibrations produce sound?

Make your hand wave back and forth quickly. Did you hear a sound? The definition of vibrate is to move back and forth quickly but you did not hear sound from your hand vibrating. Why not? The human ear is only able to detect, or hear, sound from objects that vibrate from 20 times per second to 20,000 times per second. You are unable to move your hand 20 times per second. So you cannot hear the sound from your vibrating hand. A material or an object must vibrate approximately 20 times per second for us to hear the vibrations as sound. We cannot hear sound for materials or objects vibrating more than 20,000 times per second. Consequently, the hearing range for humans is approximately 20 to 20,000 vibrations per second or hertz (Hz) although it varies by age. Hertz is the unit we will use for the number of times a material vibrates per second. This is one way to express the rate of vibration. The rate of vibration is called **frequency**. Frequency determines whether or not you can hear the sound and it also determines another characteristic of sound—pitch. More about this later.

Just because you cannot hear vibrations below 20 Hz or higher than 20,000 Hz, doesn't mean that there is no sound—you just cannot detect it. But your dog may be able to hear these sounds! Dogs can hear vibrations that range from 40 Hz to 60,000 Hz. That is why some people use a dog whistle for training. These whistles emit a sound that is above 20,000 Hz so humans cannot hear it but the dog can. The range of frequencies of sound that dogs can hear varies with age and breed.

Stop and Think: How do we hear sound from an object that is vibrating some distance away? Write down your ideas. Sometimes a sketch or diagram helps explain what you are thinking.

We have been using vibrations to describe sound. Vibrations can cause vibrations! So, when an object vibrates some distance away from you the vibrating object causes the air all around it to vibrate. This vibrating air then causes your ear drum to vibrate. Then you hear sound! We will look at this in more detail a little later but first, let's see what energy has to do with all of this.

Energy

This "transfer of vibrations" is really a transfer of energy. The transfer of vibrations is the transfer of motion, which is a transfer of energy. What is energy? Energy is an idea that is difficult to understand because in everyday language it has many meanings. But what is the scientific definition of energy?

Energy is the ability to do work.

To most of us, that definition isn't very helpful. It does not exactly match our experience of the energy we encounter when we turn on the radio or see the flash of a lightning bolt. And, of course, *work* has a particular meaning in science that is different from the way we use it in everyday language. Basically work is moving something a distance. You can think of work as simply something in motion. A moving bowling ball can do work on a set of bowling pins because it causes the pins to move (hopefully!) So the bowling ball has energy. A moving grocery cart can bump and topple a display of macaroni and cheese—so the grocery cart has energy. A vibrating tuning fork can cause air particles to move so the tuning fork has energy. We call this energy of motion, **kinetic energy**.

Look back at the definition of energy. It says "the ability" to do work. So it doesn't have to be moving. Think of a stretched rubber band, a boulder on top of a cliff, or a young girl on a swing when dad has pulled her back to start the motion. All of these objects have *the ability* to do work but they are not moving—yet. They have the potential to move and do work. Scientists call this **potential energy**. Some like to think of potential energy as stored energy.

Stop and Think: What is the relationship between energy and sound?
Hint: Remember that vibrating objects produce sound.

Moving objects have kinetic energy and vibration is a description of a rapid back and forth movement. So, this vibrating object and the surrounding vibrating air—even your vibrating eardrum, has kinetic energy. And as one vibrating object causes another to vibrate—energy is transferred or moves from one object to another.

You may have heard the phrase, “sound energy” or that sound is a “form of energy”. The Framework for K-12 Science Education, the precursor to the NGSS, clearly explains how we should think about energy and forms of energy.

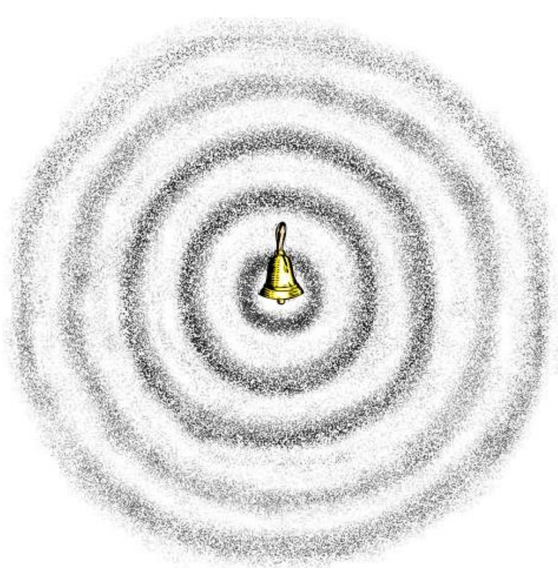
> *The idea that there are different forms of energy, such as thermal energy, mechanical energy, and chemical energy, is misleading, as it implies that the nature of the energy in each of these manifestations is distinct when in fact they all are ultimately, at the atomic scale, some mixture of kinetic energy, stored energy, and radiation. It is likewise misleading to call sound or light a form of energy; they are phenomena that, among their other properties, transfer energy from place to place and between objects.(p. 122)*

Waves of Vibrations

Let’s say you are several feet from a tuning fork and your colleague strikes the tuning fork—you hear the sound from the tuning fork. How did you hear the sound produced from a vibrating tuning fork that is several feet away? How did the sound get to your ear? You have read here that the vibrating tuning fork causes the air all around it to vibrate. (see animation) But how do the vibrations move through the air?
http://www.physicsclassroom.com/class/sound/Lesson-1/Sound-is-a-Pressure-Wave

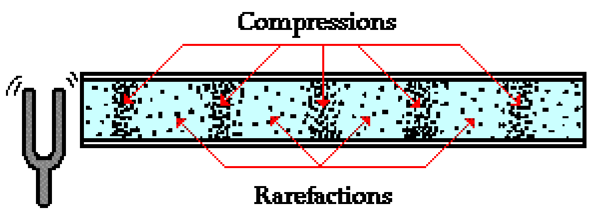
[ART RES.C2.SOU.CB.001 Illustration of tuning fork with random particles to the right.]
[ART RES.C2.SOU.CB.002 Permission to embed link in this document.]

The vibrating tuning fork is able to move particles of air. This animation and illustration only show the path of the sound in one direction—to the right of the tuning fork. In reality, the vibrations move out from the tuning fork in all directions—like a 3-dimensional sphere.
[ART RES.C2.SOU.CB.004 Illustration of circular propagation of sound waves]



This illustration is not a complete picture because sound waves propagate in three dimensions, not two like the illustration on this paper. This illustration does show that the pressure between the compressions and rarefactions is more pronounced closer to the sound source. The energy carried by the sound wave becomes more spread out the farther the wave is from the source. Some energy is also transformed to heat due to the friction between air molecules.

The vibrating tuning fork causes the air around it to vibrate creating a pressure wave that has areas of high pressure (the air particles are packed closer together) and areas of low pressure (the air particles are spread apart). These areas are labeled with the scientific term in the figure below.



Compressions are areas where there is high pressure of air particles and **rarefactions** are areas where there is a lower pressure of air particles.

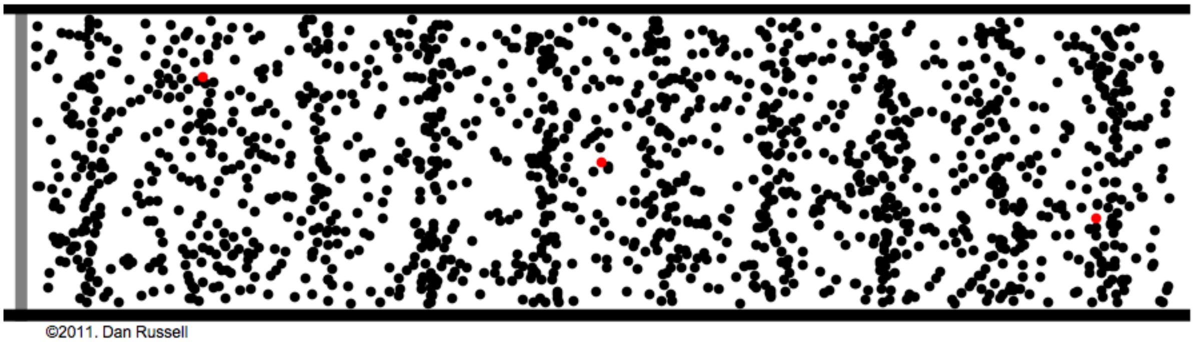
(image from [http://www.physicsclassroom.com/class/sound/Lesson-1/Sound-is-a-Pressure-Wave)](http://www.physicsclassroom.com/class/sound/Lesson-1/Sound-is-a-Pressure-Wave)

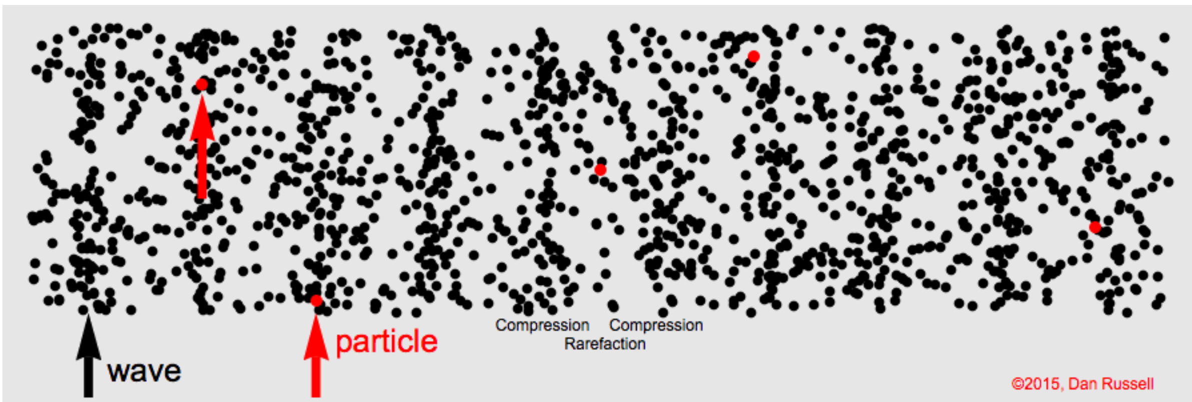
[ART RES.C2.SOU.CB.005 Illustration of tuning fork with air particles. Compressions and rarefactions are labeled.]

Stop and Think: Look at the figure below and the new animation of the same image in motion.

1. Describe the motion of one particle.
   Hint: Watch the motion of one particle. Some are shaded red to help you.
2. Describe the motion of the wave.
   Hint: Look at the moving compressed areas in the animation to help you.

[ART RES.C2.SOU.CB.006 Permission to embed link to this animation.]
[ART RES.C2.SOU.CB.007 Permission to use illustrations from the animation.]



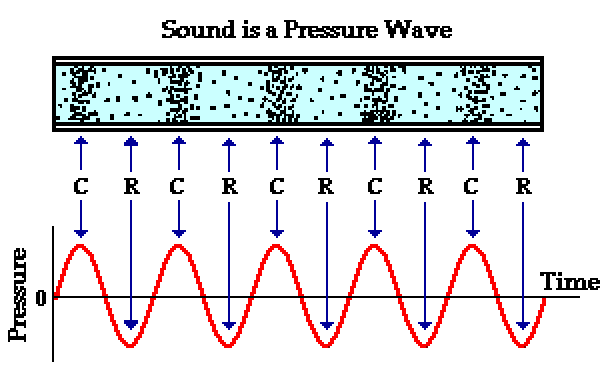


http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html

These vibrations travel as a wave. The general term for this type of wave is a **longitudinal wave**. In a longitudinal wave the particle movement is parallel to the direction of wave motion. The animation you watched shows a one-dimensional longitudinal wave moving down a tube. The particles do not move down the tube with the wave; they simply move back and forth in a set area. The wave is seen as the motion of the compressed region, which moves from left to right. You may hear waves like this also called *compressional waves* or *pressure waves*.

Pressure waves are hard to draw and in the lessons you teach, students will represent these compressional waves as a sine wave. This sine wave shows the relationship between pressure and time. You see that there is a repeating pattern of compressions (high pressure or high density) and rarefactions (low pressure or low density) in the sound wave. If this relationship were graphed on an xy graph, it would be a sine wave. Study the illustration below to see the relationship between the two graphs.

[ART RES.C2.SOU.CB.008. Illustration similar to example shown. with labels.]



The highest points of the sine wave correspond to compressions; the low points correspond to rarefactions; and the "zero points" correspond to the pressure that the air would have if there were no disturbance moving through it.

The above diagram can be somewhat misleading if you are not careful. The representation of sound by a sine wave is merely an attempt to show how the pressure changes over time. Do not conclude that sound is a transverse wave (described in the next paragraph) that has crests and troughs. Sound waves traveling through air are indeed longitudinal waves with compressions and rarefactions

Stop and Think: How would the longitudinal wave for a loud sound look different from a quiet sound? How would the sine wave representation look different for a loud sound and a quiet sound?

Hint: Draw a sketch of each type of wave for a loud and a quiet sound.

Waves moving through water, waves on a rope as you jiggle it back and forth, and the motion of the strings in a guitar are all different from sound waves—they transfer energy as transverse waves. In **transverse waves**, the motion of the matter in the wave is perpendicular to the motion of the wave. Imagine sitting next to the ocean and watching the water. The surface of the water probably is not flat and mirror like. Rather, the surface of the water probably has a variety of ripples, waves, or swells. As the waves move through the water, they transport energy. You can see this as the waves move to the beach and crash on the shoreline.

Now imagine floating on the water in a kayak. As a wave passes, you bob up and down. The wave moves to the shore. The motion of the molecules of water is similar. This water wave is a transverse wave where the motion of the water molecules (or you and your kayak!) move perpendicular (up and down) to the motion of the wave (toward the shore). Transverse waves are shaped like sine waves and have crests and troughs as shown below.
[ART RES.C2.SOU.CB.009 Illustration of transverse wave with crests and troughs labeled.]

Sound waves and Properties of Sound Waves

In the lessons that you will teach your students, they will consider only one property of sound—its volume. Your students will not be responsible for naming this property but will come to understand that sounds can be different in how loud or quiet they are. Your students will only consider the relative volume of sound—in other words, they will only compare one sound to another and determine if the sound is louder or quieter than the other sound. Loudness or quietness is a human perception of sound and can be very subjective. Your idea of a loud sound may not seem loud at all to your first graders!

Have you ever told your students to turn down their MP3 player or the volume on their tablet? If so, they adjusted the volume on these devices. The only thing that changed about the sound coming from these devices was the loudness. The student changed the *intensity* of the sound—it changed the vibrations producing the sound too. Intensity can be measured and so is not as subjective as volume. Intensity is related to the energy of the sound—more energy, more intensity. In the sound wave, if the sound is very intense then the compressions in the wave would be highly compressed and the rarefactions would have very low pressure. Sound with a high intensity would be considered a loud sound.

Stop and Think: How would the vibrations producing a loud sound be different from the vibrations producing a quiet sound?

Bigger vibrations produce louder sounds with greater energy and smaller vibrations produce quieter sounds with lower energy. Think back to the vibrating tuning fork and the animation of the surrounding air. If you could change the vibrations to be bigger vibrations, you can imagine how the vibrating tuning fork could create areas that are very compressed—more than when the tuning fork was vibrating before you increased the vibrations. How can you cause the tuning fork to vibrate more? Strike the tuning fork with more energy!

Stop and Think:

1. What would a pressure-time wave or sine wave (**[ART RES.C2.SOU.CB.0010 Illustration of a sine wave**) look like for a very loud sound compared to a very quiet sound? In the two boxes below, draw what you think the waves will look like. Draw the same number of waves ("humps" for sine waves and compressions for pressure waves) in each box. The boxes represent the same amount of time.

2. How does your drawing here compare to the drawing you did earlier?

quiet sound	loud sound

Louder sounds have higher intensity and also larger amplitudes. Intensity of sound is measured in decibels (db). **Amplitude** is easy to measure on a wave drawn as a sine wave. You simply measure from the highest point in the wave (or lowest point) to the rest position. In a sound wave you must measure a particle's maximum displacement from the rest position—hard to do when the particles are atoms and molecules! So, it is much easier to measure amplitude of a wave when the wave is drawn as a sine wave.

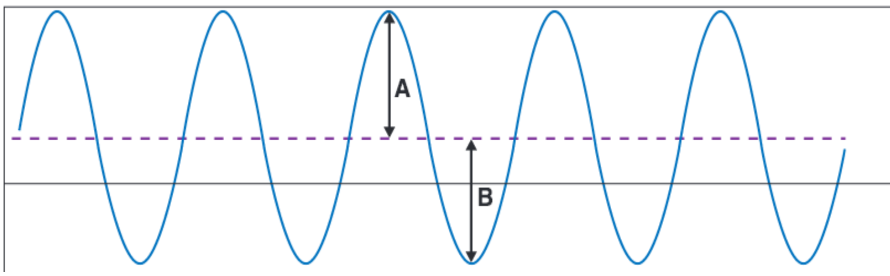


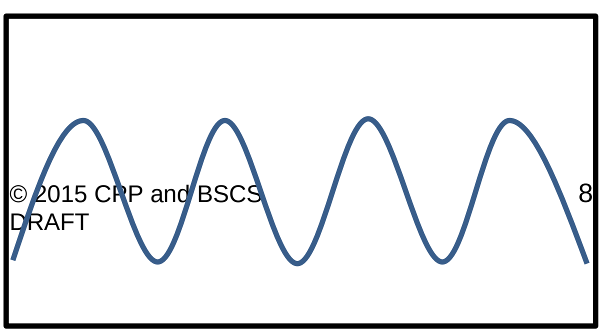
Figure 10.13
Amplitude of a wave. You can measure the amplitude by measuring distance A or distance B.

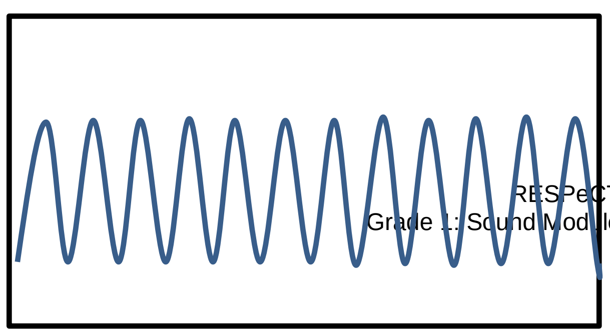
(image from BSCS Science: An Inquiry Approach Level 1 pg 477)

[ART RES.C2.SOU.CB.011 Illustration of sine wave with amplitude measurements shown as in this image.]

Another property of sound is pitch. Pitch is not part of the content of the module that you will teach your students, but the idea might come up in discussions. Young children have difficulty distinguishing between pitch and loudness. This is one of the reasons we chose to limit the properties in this module to volume only. **Pitch** is the highness or lowness of sound. This property of sound is related to the frequency of sound. **Frequency** is the number of back and forth motions or vibrations in a set amount of time—usually per second. In other words, frequency is how many waves pass a given point in one second. We usually talk about the number of waves per second and when we do, the unit of frequency is hertz (Hz). One Hz = 1 wave/second. The illustration below shows two different waves, one with a low frequency and one with a high frequency. All the blocks represent the same amount of time and the x-axes in the diagrams represents time.

(filled in with corresponding pressure wave art)	(filled in with corresponding pressure wave art)





low frequency
low pitch

high frequency
high pitch

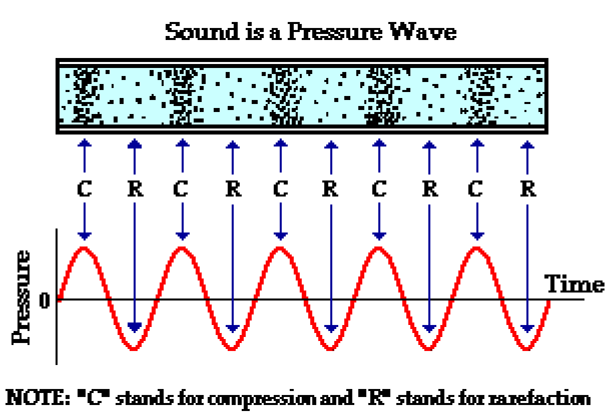
[ART RES.C2.SOU.CB.012. Illustration of four squares with waves both sine and pressure wave.]

Stop and Think: How does the loudness of the two waves compare? How can you tell?

How does frequency and energy compare? You learned earlier that waves with higher amplitude transfer more energy than waves with a lower amplitude. You can imagine making waves with a rope. You would have to use more energy to make bigger waves (waves with higher amplitude). Now think about making waves on a rope again like the two different waves shown in c and d of the diagram above, which wave would you have to use more energy to make? Waves with higher frequency transfer more energy than waves with lower frequency.

Notice in the figure below that the **wavelength** (measured from one point on a wave to the corresponding point on the adjacent wave) is shorter for high frequency waves and longer for low frequency waves. Look at the figure below to see how wavelength is measured in both types of waves. This relationship between wavelength and frequency holds true if the waves are traveling at the same speed. Speed is measured as the distance a wave travels divided by the time it took. The speed of sound in air varies with the properties of the air. Two properties of air that can affect the speed of sound are density and temperature. Sound travels faster in warmer air than in cooler air. In warmer air, the molecules are moving faster and bump into each other more often and can therefore transmit the sound wave in less time. The speed of sound increases about 0.6 m/s with each degree Celsius rise in temperature.

If the sound is traveling through substances other than air the speed depends on the properties of the material. The average speed of sound in air at room temperature is 340 m/s but the average speed of sound through steel is about 5,200 m/s!



[ART RES.C2.SOU.CB.013. Same illustration as CB.008 but with C and R labels removed and wave length measurements added.]

Stop and Think: Try this—draw a sine wave in each of the boxes below to represent a sound that is described below the box. All boxes represent the same amount of time and all waves are travelling at the same speed.

(high pitched quiet sound)

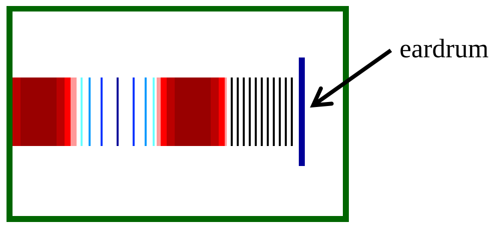
(low pitched quiet sound)

(high pitched loud sound)

(low pitched loud sound)

Hearing Sound

A sound maker vibrates and causes the air around it to vibrate. Once these vibrations in air reach your ear, you hear sound. How does that work? Well, vibrating air can also make other objects vibrate—your eardrum for example. (see the animation below)

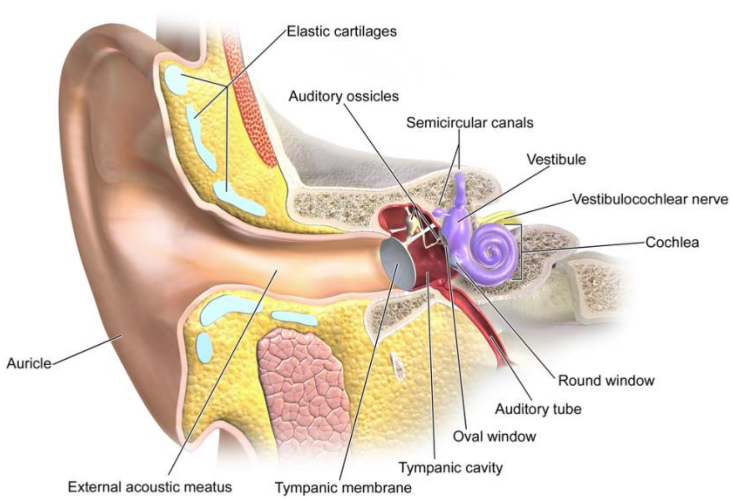


[ART RES.C2.SOU.CB.014 Permission to embed animation link]

[ART RES.C2.SOU.CB.015 Permission to use this image for the link.]

http://www.physicsclassroom.com/mmedia/waves/edl.cfm

When a pressure wave reaches the ear, the series of high and low pressure regions interact with your eardrum. This causes the eardrum to vibrate. The vibrations then cause the bones of the middle ear—the hammer, anvil, and stirrup to vibrate. These vibrations then cause the fluid in the inner ear to vibrate. In the inner ear, the vibrations are converted to electrical nerve impulses which are sent to the brain. Your brain turns all these vibrations to sound—amazing!



The Anatomy of the Ear

http://en.wikipedia.org/wiki/Ear

[ART RES.C2.SOU.CB.016 Image of the inner parts of the ear with labels matching the text.]

Stop and Think:

1. The Central Unit Question for the module you will teach your students is, *Why do we hear sound?* Answer this question using what you have learned about sound.
2. Can sound travel (move) through a vacuum? (In a vacuum, there is no matter—not even air) Explain your answer.